Application of Adaptive Optics and Compensation of Chromatic Aberration at the Petawatt Laser PHELIX

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PHELIX (Petawatt High Energy Laser for Heavy-Ion Experiments) is an acronym for a laser with a peak power of one petawatt (1 PW = 10^{15} Watt) which is currently built at the Gesellschaft für Schwerionenforschung (GSI) in Darmstadt. After its completion, PHELIX will have a pulse energy of 500 J with a pulse duration of 500 fs.

This thesis presents the results of the investigations on the spatial and temporal aberrations of the PHELIX-laser. The focus is put on the compensation of spatial aberrations with adaptive optics and the characterisation of the influence of chromatic aberrations on the temporal pulse structure.

Spatial aberrations result e.g. from an in-perfect surface quality of the laser mirrors or compromises in the optical set-up. However, the largest portion of spatial aberrations result from thermo-optical aberrations. Adaptive optics allow the compensation of these thermo-optical aberrations. An adaptive mirror with an actively controlled surface is placed in the beamline. Currently, the mirror control signal is directly calculated out of a wavefront measurement. With this closed-loop system, the compensation of thermo-optical aberrations at PHELIX was demonstrated.

Within the scope of this thesis, a second closed-loop system was developed, based on an evolutionary search algorithm. This new control algorithm allows the calculation of the optimal adaptive mirror surface from an intensity measurement of the laser pulse. This parameter is more easily to measure than the wavefront of the pulse. The search algorithm had not been tested at PHELIX but could be demonstrated at two experimental set-ups.

A PHELIX laser pulse passes several lenses with a beam diameter of 300 mm. These lenses cause chromatic aberrations which lead to a delay between the center and the edge of the pulse. To predict the influence of the chromatic aberration in the focal spot, a numerical model was developed which allows to calculate the propagation of ultrashort pulses through an optical system with an arbitrary intensity distribution and arbitrary spatial phase aberrations. For PHELIX, the intensity decrease in the focal spot caused by chromatic aberration is around 35%. Two concepts were developed to pre-compensate the chromatic aberration. In one of these concepts, a positive diffractive lens and a negative refractive lens are combined to a nearly non-magnifying telescope. The dispersion of refractive lenses is opposite and around 30 times larger than those of refractive lenses. This allows pre-compensation of chromatic aberration with a beam diameter of 2 cm onwards. In order to allow measuring of the pulsfront delay in the amplifier chain, a self-referencing auto-correlator was developed.